Ministry of Natural Resources

25

CLIMATE CHANGE RESEARCH REPORT CCRR-25

Vulnerability of Furbearers in Ontario's Clay Belt to Climate Change

Responding to Climate Change Through Partnership

Ontario

Sustainability in a Changing Climate: An Overview of MNR's Climate Change Strategy (2011-2014)

Climate change will affect all MNR programs and the natural resources for which it has responsibility. This strategy confirms MNR's commitment to the Ontario government's climate change initiatives such as the Go Green Action Plan on Climate Change and outlines research and management program priorities for the 2011-2014 period.

Theme 1: Understand Climate Change

MNR will gather, manage, and share information and knowledge about how ecosystem composition, structure and function – and the people who live and work in them – will be affected by a changing climate. Strategies:

- Communicate internally and externally to build awareness of the known and potential impacts of climate change and mitigation and adaptation options available to Ontarians.
- Monitor and assess ecosystem and resource conditions to manage for climate change in collaboration with other agencies and organizations.
- Undertake and support research designed to improve understanding of climate change, including improved temperature and precipitation projections, ecosystem vulnerability assessments, and improved models of the carbon budget and ecosystem processes in the managed forest, the settled landscapes of southern Ontario, and the forests and wetlands of the Far North.
- Transfer science and understanding to decision-makers to enhance comprehensive planning and management in a rapidly changing climate.

Theme 2: Mitigate Climate Change

MNR will reduce greenhouse gas emissions in support of Ontario's greenhouse gas emission reduction goals. Strategies:

- Continue to reduce emissions from MNR operations though vehicle fleet renewal, converting to other high fuel efficiency/low-emissions equipment, demonstrating leadership in energy-efficient facility development, promoting green building materials and fostering a green organizational culture.
- Facilitate the development of renewable energy by collaborating with other Ministries to promote the value of Ontario's resources as potential green energy sources, making Crown land available for renewable energy development, and working with proponents to ensure that renewable energy developments are consistent with approval requirements and that other Ministry priorities are considered.
- Provide leadership and support to resource users and industries to reduce carbon emissions and increase carbon storage by undertaking afforestation, protecting natural heritage areas, exploring opportunities for forest carbon management to increase carbon uptake, and promoting the increased use of wood products over energy-intensive, non-renewable alternatives.
- Help resource users and partners participate in a carbon offset market, by working with our partners to ensure that a robust trading system is in place based on rules established in Ontario (and potentially in other jurisdictions), continuing to examine the mitigation potential of forest carbon management in Ontario, and participating in the development of protocols and policies for forest and land-based carbon offset credits.

Theme 3: Help Ontarians Adapt

MNR will provide advice and tools and techniques to help Ontarians adapt to climate change. Strategies include:

- Maintain and enhance emergency management capability to protect life and property during extreme events such as flooding, drought, blowdown and wildfire.
- Use scenarios and vulnerability analyses to develop and employ adaptive solutions to known and emerging issues.
- Encourage and support industries, resource users and communities to adapt, by helping to develop understanding and capabilities of partners to adapt their practices and resource use in a changing climate.
- Evaluate and adjust policies and legislation to respond to climate change challenges.

Vulnerability of Furbearers in Ontario's Clay Belt to Climate Change

Jeff Bowman and Carrie Sadowski

Wildlife Research and Development Section, Ontario Ministry of Natural Resources, Trent University, DNA Building, 2140 East bank Drive, Peterborough, ON, K9J 7B8

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Applied Research and Development
Ontario Forest Research Institute
Ministry of Natural Resources
1235 Queen Street East
Sault Ste. Marie, ON
Canada P6A 2E5

Telephone: (705) 946-2981
Fax: (705) 946-2030
E-mail: information.ofri@ontario.ca

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Abstract

We assessed the vulnerability of furbearers in the Clay Belt to climate change. We identified four processes leading to vulnerability: the introduction of southern competitors and pathogens, increased extinction risk of cold-adapted species, selection for early breeding, and reduced synchrony. Potential indicators of these processes include the distribution and abundance of temperate species, such as the raccoon (*Procyon lotor*) and the distribution and abundance of cold-adapted species, such as the American marten (*Martes americana*) and Canada lynx (*Lynx canadensis*). Other indicators include changes in the seasonal timing of breeding in rodents such as the muskrat (*Ondatra zibethicus*) and changes to the frequency and amplitude of the lynx-snowshoe hare (*Lepus americanus*) cycle. Overall, we anticipate that climate change will result in the Clay Belt and its constituent furbearer species becoming more temperate in character.

Résumé

Vulnérabilité des animaux à fourrure dans la région de la ceinture d'argile en Ontario aux changements climatiques

Nous avons évalué la vulnérabilité des animaux à fourrure de la région de la ceinture d'argile aux changements climatiques. Nous avons cerné quatre processus menant à la vulnérabilité : introduction de concurrents et de pathogènes en provenance du Sud, risque accru de disparition des espèces adaptées au froid, sélection pour une reproduction précoce et réduction de la synchronisation. Parmi les indicateurs potentiels de ces processus, on retrouve la distribution et l'abondance d'espèces tempérées comme le raton laveur (Procyon lotor), ainsi que la distribution et l'abondance d'espèces adaptées au froid comme la martre d'Amérique (Martes americana) et le lynx du Canada (Lynx canadensis). Autres indicateurs : changements du moment de la saison où les rongeurs comme le rat musqué (Ondatra zibethicus) se reproduisent et de la fréquence et de l'ampleur du cycle du lièvre d'Amérique (Lepus americanus). En règle générale, nous prévoyons que des changements climatiques surviendront dans la région de la ceinture d'argile et que le caractère des espèces d'animaux à fourrure qui y vivent sera plus tempéré.

Acknowledgements

We thank Aaron Walpole for assistance, Brian Shuter and Ken Minns for providing ice data, Bruce Pond for providing raccoon harvest data, the Canadian Forest Service for providing climate data, and the Applied Research and Development Branch for funding. Gilbert Racine of the Northeast Geomatics Service Centre developed mapping products to support the project. We thank Paul Gray and Aaron Walpole for reviewing an earlier version of the manuscript and Trudy Vaittinen for report production support.

Foreword

This is one in a series of reports to help resource managers evaluate the vulnerability of natural assets to climate change. Given that vulnerability assessment techniques continue to evolve, it is important for resource managers to learn by doing and to pass on knowledge gained to support the Ontario Ministry of Natural Resources and others engaged in adaptive management. Accordingly, the vulnerability assessment reports included in the Climate Change Research Report Series have been prepared using the best available information under the circumstances (e.g., time, financial support, and data availability). Collectively, these assessments can inform decision making, enhance scientific understanding of how natural assets respond to climate change, and help resource management organizations establish research and monitoring needs and priorities.

Cameron Mack

Acting Director, Applied Research and Development Branch

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1.0 Introduction

Vulnerability assessments can be an important component of a climate change adaptation strategy (Gleeson et al. 2011). In the context of climate change, vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, the effects of environmental change, including climate variability and extremes (IPCC 2007a). Identifying vulnerabilities can allow strategies to be developed that can be used to improve the adaptive capacity of systems.

As one contribution to an overall Clay Belt (also referred to as Ecodistrict 3E-1; Fig. 1) climate change vulnerability assessment (Lalonde et al. 2012), we were asked to focus on the theme of furbearers. Furbearer is not a taxonomic designation, but rather a label applied to a group of mammals (mostly rodents and carnivores) that are harvested for fur. As such, the collection of species is really a legislative and management construct rather than an ecological one so furbearers do not constitute an ecological system per se. We have taken the approach of considering the vulnerability of the contemporary community of furbearer species that occur in the Clay Belt (Table 1).

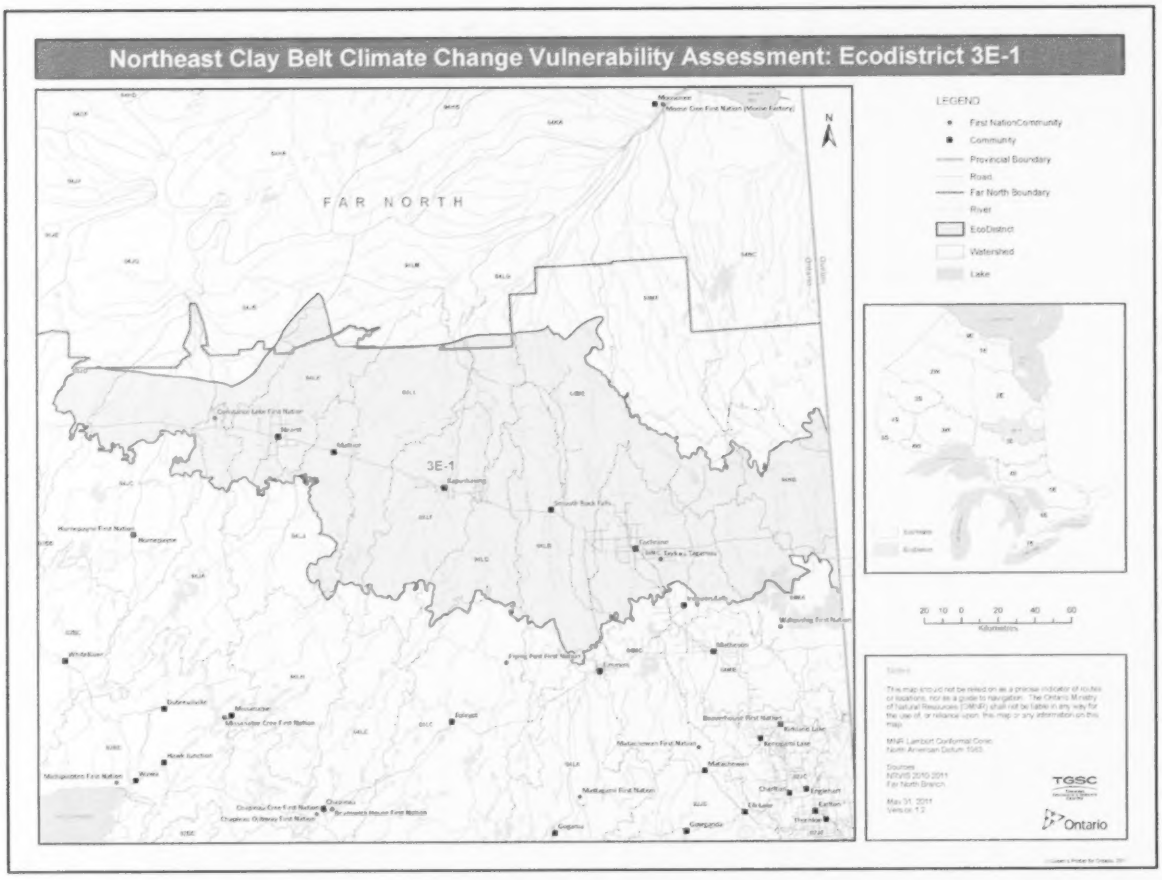

Figure 1. *Location of Ecodistrict 3E-1 (Crins et al. 2009), also known as the Clay Belt, in Ontario.*

In both Canada and Ontario, furbearers play an important socioeconomic role. The fur trade was a catalyst in the exploration of Canada by early European settlers. Today, its historical importance is underscored by recognition of the beaver as a national symbol. In Ontario, about 200,000 pelts are harvested and sold annually by trappers, with their annual value exceeding $5 million (5-year average 2004-2008; Statistics Canada 2008). About 330 traplines are registered in the Clay Belt.

Furbearer species also play a vital ecological role. For example, the beaver has been considered a keystone species (Novak 1987), and the furbearer designation includes several prominent predator and prey species, from the iconic wolf to the diminutive weasel (Table 1).

Our main objective was to assess the vulnerability of the furbearer community in the Clay Belt to climate change. We did this by evaluating both present and future vulnerabilities of the community to climate and non-climate stressors.

Table 1. *Ontario furbearer species. Bold type indicates species that presently occur in the Clay Belt area of Ontario.*

Common Name	Latin Name
American badger	*Taxidea taxus*
American marten	***Martes americana***
Arctic fox	*Vulpes lagopus*
Beaver	***Castor canadensis***
Black bear	***Ursus americanus***
Bobcat	*Lynx rufus*
Canada lynx	***Lynx canadensis***
Coyote	***Canis latrans***
Eastern cougar	*Puma concolor*
Eastern wolf	*Canis lycaon*
Fisher	***Martes pennanti***
Gray fox	*Urocyon cinereoargenteus*
Gray wolf	***Canis lupus***
Least weasel	***Mustela nivalis***
Long-tailed weasel	*Mustela frenata*
Mink	***Neovison vison***
Muskrat	***Ondatra zibethicus***
Polar bear	*Ursus maritimus*
River otter	***Lutra canadensis***
Raccoon	***Procyon lotor***
Red fox	***Vulpes vulpes***
Red squirrel	***Tamiasciurus hudsonicus***
Short-tailed weasel	***Mustela erminea***
Striped skunk	***Mephitis mephitis***
Virginia opossum	*Didelphis virginiana*
Wolverine	*Gulo gulo*

Methods

To select indicators of vulnerability within the furbearer theme, we followed up on recent work by Walpole and Bowman (2012), who identified seven processes leading to wildlife vulnerability to climate change (Table 2). These are not processes leading to species vulnerabilities (e.g., Varrin et al. 2007), but rather to vulnerabilities of a place and its constituent species and systems (i.e., vulnerability of a place rather than a species). Although Walpole and Bowman (2012) were assessing vulnerabilities in a particular watershed (Lake Simcoe, Ontario), the processes they identified should be generally applicable to locations in the northern hemisphere. Thus, we used this list as a starting point from which to select indicators of furbearer vulnerability to climate change within the Clay Belt.

Our approach was to use a combination of literature review, data analysis (where possible), and climate envelope scenario modelling (where possible) to evaluate each of the processes leading to potential vulnerability of furbearers to climate change in the Clay Belt. Climate change projections used the Canadian General Circulation Model Version 3 (CGCM3) (Canadian Centre for Climate Modelling and Analysis) and a combined model, referred to as the ensemble model, for the periods 2011 to 2040, 2041 to 2070, and 2071 to 2100, under both the A2 and B1 climate change scenarios. The ensemble model was created by combining outputs of four general circulation models:

- Canadian General Circulation Model 3 (CGCM3);
- U.S. National Center for Atmospheric Research (NRCAR-3 model);
- Japanese Model for Interdisciplinary Research on Climate (MIROC32); and
- Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO model).

The B1 scenario represents a world that is environmentally focused with lower emission levels than the A2 scenario where high emission levels are driven by rapid economic development (IPCC 2007b). Contemporary climate data (1971-2000) and the two climate model data sets were provided by the Canadian Forest Service. Other data sources are cited with their usage in the text.

***Table 2**. Processes leading to vulnerability of wildlife to climate change within a geographical region.*

Process	Assessed for Clay Belt?
Introduction of southern competitors and pathogens	Yes
Increased extinction risk of cold-adapted species	Yes
Selection for early breeding	Yes
Reduced synchrony in ecological systems	Yes
Increased interspecific hybridization	No
Selection for species able to rapidly move through fragmented landscapes	No
Selection for high genetic variability for fitness related traits	No

Results

Based on our review of available evidence and data, we omitted three of the processes listed in Table 2 from further consideration in the Clay Belt vulnerability assessment. The first of these processes is hybridization. Although wolves do hybridize in Ontario (Wilson et al. 2009), the links between climate change and wolf hybridization are not clear. A more obvious example of the potential for climate-change induced hybridization occurs between the sister species Canada lynx (*Lynx canadensis*), which have a northern distribution, coincident with the boreal forest, and bobcat (*Lynx rufus*), which have a more southern, temperate distribution. Hybridization has been demonstrated between these two species, but it appears to be rather rare within the species pair (Schwartz et al. 2004, Homyack et al. 2008). Although it is possible that lynx × bobcat hybrids may appear in the Clay Belt as the bobcat expands its range north, we anticipate that hybrids will remain relatively rare, and that the process of hybridization will be relatively less important than competition between lynx and bobcat.

A second process that we are omitting from further consideration is the selection for species able to rapidly move through fragmented landscapes. Walpole and Bowman (2012) considered this process to be highly important across the suite of all wildlife species in the fragmentated landscapes around Lake Simcoe. However, furbearers are rather vagile, and already adapted to large-scale disturbance in the boreal forest of the Clay Belt. For example, Koen et al. (2012) found that American marten (*Martes americana*) gene flow in Ontario was not limited by landscape resistance, and Row et al. (2012) have shown that the Canada lynx is genetically panmictic across Canada, with the sole exception of insular Newfoundland. As such, we do not anticipate that dispersal of furbearers will be limited within a relatively small area of boreal forest such as the Clay Belt.

The last of the three processes that we are omitting from the vulnerability assessment is the selection for high genetic variability for fitness-related traits. Although this variability is undoubtedly important during periods of rapid environmental change (Berteaux et al. 2004), data are presently insufficient to evaluate genetic variability of fitness traits for furbearers in the Clay Belt.

In the rest of the results section, we review each of the remaining processes leading to vulnerability and identify potential related indicators.

Introduction of southern competitors and pathogens

With increasing temperatures, we anticipate an increase in the number of mammal species in Ontario, due to increased available energy in the environment. Kerr and Packer (1998) showed that mammalian species richness in Canada can be predicted by mean annual temperature as:

$$\text{Mammal species richness} = 1.960 \times (\text{mean annual temperature in } ^\circ\text{C}) + 38.1 + \varepsilon,$$

where ε is the residual variance. When combined with the ensemble climate model (under scenario A2), predictions from the species-energy relationship indicate that in the Clay Belt region mammal species richness will increase 28% by the year 2100, with increases directly linked to increases in mean annual temperature. Model results suggest that current climate conditions support a community of approximately 39 mammal species and that this number may increase to 44 species by 2011 to 2040, 46 species by 2041 to 2070, and 50 species by 2071 to 2100.

In the context of furbearers in the Clay Belt, the species-energy relationship suggests that increased species richness should result from species colonizing the Ecodistrict from the south. Furbearer species with largely temperate distributions should be able to expand their ranges north due to ameliorating winter conditions. For example, increased winter survival of the Virginia opossum (*Didelphis virginiana*) (Wiseman and Hendrickson 1950, Brocke 1970, Tyndale-Biscoe and MacKenzie 1976) should result in rapid range expansion such that the opossum distribution will likely be much closer to the Clay Belt by 2100 than it is now (Fig. 2).

Changes in winter conditions may also mean that some species that already occur in the Clay Belt, but at low population densities, will become more abundant. For example, raccoon (*Procyon lotor*) abundance is greatest

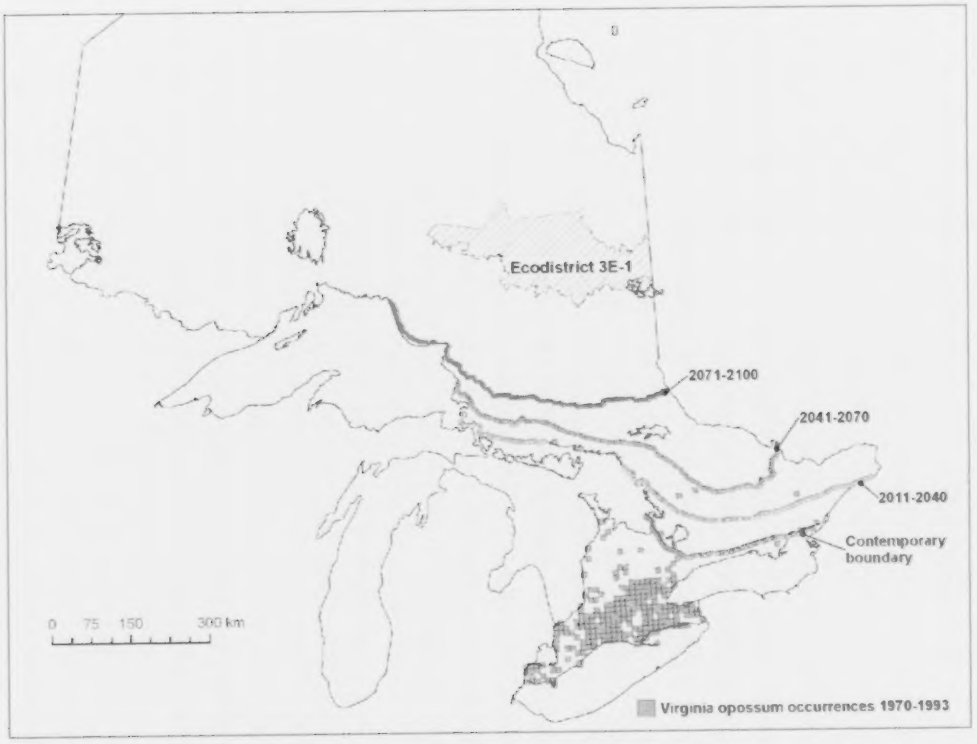

Figure 2. *Future northern range boundary scenarios for the Virginia opossum (Didelphis virginiana) in Ontario based on the -12 °C minimum January isotherms for current and future climate scenarios as projected using the CGCM3 climate model (A2 scenario). Virginia opossum occurrences are based on the 1970 to 1993 Atlas of the Mammals of Ontario data (Dobbyn 1994).*

in relatively southern areas with a temperate climate (Fig. 3), but it occurs in the Clay Belt at low densities, and its range appears to be expanding north, at least partly due to changes in climate (Voigt et al. 2000). We expect that raccoon densities will increase in the Clay Belt in the future. Overall, we should see an increase in the distribution and abundance of all temperate furbearers in the Clay Belt, including species such as bobcat, fisher (*Martes pennanti*), raccoon, striped skunk (*Mephitis mephitis*), and even potentially the opossum.

In parallel with increased mammal richness as the climate warms is an expected increase in pathogens. Many pathogens are limited at their northern range edge by cold winters, and thus are expected to advance north under climate change. One well known example from Ontario is Lyme disease, and its tick vector, *Ixodes scapularis* (Ogden et al. 2006, Varrin et al. 2007). Raccoons are host to a roundworm, *Baylisascaris procyonis*, that can be a fatal human pathogen (Box 1), and which may become more prevalent in the Clay Belt as raccoon densities increase. Indeed, *B. procyonis* has been identified as one of the "deadly dozen" human pathogens thought to be affected by climate change (Wildlife Conservation Society 2008). It also causes disease in many other wildlife species (Kazacos 2001). Numerous other pathogens, such as raccoon rabies and canine distemper, are associated with furbearers and may become more prevalent farther north as the climate changes.

Increased extinction risk of cold-adapted species

Under a warming climate, species adapted for cold and northern environments may have reduced fitness. MacArthur (1972) suggested that in the northern hemisphere, species geographic ranges should be limited at their southern edge by biotic factors such as competition, predation, and disease. So fitness reductions in cold-adapted species from the Clay Belt may not be direct effects of climate limitation, but rather indirect effects

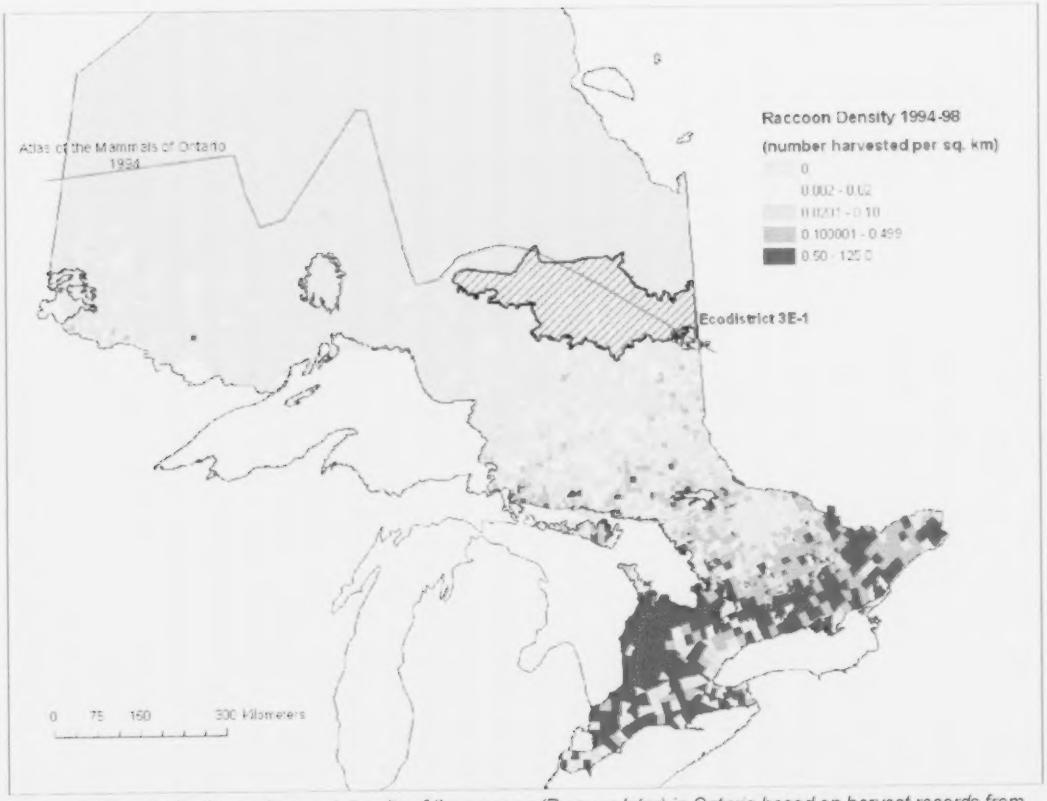

Figure 3. *The distribution and harvest density of the raccoon (Procyon lotor) in Ontario based on harvest records from 1994 to 1998. An approximate northern range boundary based on the 1970 to 1993 Atlas of the Mammals of Ontario (Dobbyn 1994) is also shown.*

of other biotic changes associated with climate. For example, evidence exists that the marten is competitively excluded from environments with no or little snow by the congeneric fisher (Krohn et al. 1995, 1997). The fisher appears limited by deep snow due to inefficient foot-loading; however, marten foot-loading is relatively efficient, so that martens appear well-adapted to deep snow environments. Thus, the competitive interaction between fisher and marten may be mediated by deep snow. If climate warming leads to reduced snow depth, we may anticipate an increase in fisher populations to the detriment of the cold-adapted marten. The lynx and bobcat appear to have a similar competitive relationship mediated by foot-loading and snow depth (Buskirk et al. 2000, Krohn et al. 2004).

Selection for early breeding

The onset of breeding in many carnivore species is regulated by photoperiod and its effects on neuroendocrine pathways (Bronson 2009). As environments change rapidly, species that cannot evolve new seasonal strategies may face population declines and local extinctions (Bradshaw and Holzapfel 2006). However, since photoperiod is invariant with changing climates, potential is limited for species with seasonal breeding strategies under photoperiodic control to adapt breeding schedules in response to climate change. On the other hand, shorter-lived species such as many rodents have other triggers for breeding, and in many cases these triggers may be climate-related. One well known example of a species that shows evidence of evolving its breeding schedule with climate warming is the red squirrel (*Tamiasciurus hudsonicus*). In the Yukon, the red squirrel advanced its breeding date by 18 days during a 10-year study, due to indirect effects of climate (Réale et

al. 2003). Warmer weather led to an increased food supply for red squirrels, which in turn led to earlier breeding. The changes in red squirrel breeding date were shown to be at least partly heritable (Réale et al. 2003).

In another rodent species, the muskrat (*Ondatra zibethicus*), breeding appears to begin immediately following spring thaw (Errington 1963). Thus, earlier thaws will facilitate earlier breeding in muskrats, and also potentially multiple litters, as muskrats can have as many as five litters in a season (Errington 1963). Some climate model scenario results indicate that ice-out dates will occur earlier in the future, and thus that muskrat breeding will also occur earlier in the spring. This may eventually conflict with the current legislated harvest seasons for muskrat, such that trapping might continue to occur after adults have given birth, potentially resulting in the orphaning of neonates.

Reduced synchrony in ecological systems

To date, the balance of evidence suggests that synchrony of systems will be reduced during periods of rapid environmental change. For example, Visser and Both (2005) found that in seven of 11 studies with appropriate data, synchrony between predator and prey or host and parasite was reduced due to climate change. For furbearers in the Clay Belt, perhaps the most obvious synchronous system is the well-known cycle between Canada lynx and snowshoe hare (*Lepus americanus*). Indeed, some historical evidence shows that synchrony between lynx and hare is greatest during cold periods, and that cyclicity breaks down during periods of warming (Scott and Craine 1993). This pattern may arise due to an increase in specialized predation during cold periods. Furthermore, contemporary patterns show that lynx cycles are most pronounced at the north edge of their range, and tend towards non-cyclicity at the south edge of their range (Guillaumet, Bowman, and Murray, unpublished data). Lynx populations also exhibit a greater tendency to cycle than their southern sister species, the bobcat (Guillaumet, Bowman, and Murray, unpublished data).

What is *Baylisascaris procyonis*?[1]

Baylisascaris procyonis is a common roundworm of raccoons that can fatally infect humans. The adult worms live in the small intestine of the raccoon, and female worms shed eggs into a raccoon's intestinal tract, which then pass into the environment with the feces of the host. Millions of eggs may be present in a single defecation. The eggs are not immediately infective and must incubate for a period of time, typically 11 to 21 days depending on temperature and humidity. Larvated eggs are extremely resistant to physical and chemical attack and can remain infective in the environment (e.g., in soil) for years. If larvated eggs are ingested by an animal other than a raccoon, they may migrate through body tissues, causing extensive damage as they travel. This may result in severe illness or death of the affected host.

This parasite likely occurs wherever raccoons are present, but its prevalence varies widely across the raccoon's range. A large study in Indiana over a six-year period found 72% of raccoons to be infected with *B. procyonis*, with higher rates of infection found in juvenile raccoons (Kazacos 2001). A small study in southern Ontario found that 51% of raccoons were infected (Berry 1985), but no systematic surveys have been reported of the parasite's occurrence in Canada. The worm is relatively harmless to raccoons, but neurological disease due to tissue migration of *B. procyonis* is a common cause of death in rabbits, squirrels, groundhogs and other rodents, as well as some species of ground-foraging birds. Infection outbreaks can have population-level effects, particularly in small or isolated populations, which has implications for threatened and endangered species (Kazacos 2001).

Only a small number of cases of human infection with *B. procyonis* have been reported, but the consequences have been extremely severe. Migrating larval worms will typically enter the brain, resulting in neurological impairment and possibly death. Humans, most often young children, generally become infected from accidentally ingesting eggs from soil, water, hands, or other objects contaminated with raccoon feces. In people the disease is not easily diagnosed and is essentially untreatable. Human infection by this parasite is an emerging issue that may be a more important public health problem than is currently recognized, as raccoons are increasingly living in close proximity to humans and are among the fastest growing wildlife populations in North America (Sorvillo et al. 2002).

[1]Except where otherwise cited, information obtained from the Canadian Cooperative Wildlife Health Centre, 2011.

Discussion

We have identified four main processes that may result in furbearers in the Clay Belt being vulnerable to climate change, and these processes suggest a variety of possible indicators (Table 3). Overall, we expect that the suite of furbearer species in the Clay Belt should increase as the climate warms, as temperate species arrive from the south to colonize the region or their population density increases. A variety of temperate species and pathogens, such as raccoons and the raccoon roundworm, would make useful indicators of this process of colonization. A reduction in the distribution of cold-adapted species, such as lynx and marten, may occur due to increased competition with colonizing species. The net change of this species turnover should be an increase in mammalian richness in the Clay Belt due to the availability of greater energy in the environment (Kerr and Packer 1998). Phenological changes will also contribute to changes in species distributions and earlier breeding dates, which may provide many rodent species with a selective advantage compared to many carnivore species whose breeding initiation is under photoperiodic control. Many rodent species appear to initiate breeding as a result of climate cues rather than photoperiod, and thus species such as the muskrat and the red squirrel appear well situated to adapt their breeding schedules as the climate changes. Finally, synchrony of systems in the Clay Belt should be reduced by rapid climate change, an effect that may alter the iconic lynx-hare cycle.

***Table 3**. Potential indicators of furbearer vulnerability to climate change in the Clay Belt region of Ontario resulting from climate change-facilitated processes.*

Process	Indicator
Introduction of southern competitors and pathogens	Distribution of Virginia opossum Distribution of bobcat Distribution and abundance of fisher Distribution and abundance of raccoon Distribution and prevalence of raccoon roundworm, *Baylisascaris procyonis*
Increased extinction risk of cold-adapted species	Distribution and abundance of Canada lynx Distribution and abundance of American marten
Selection for early breeding	Onset of breeding in muskrat Onset of breeding in red squirrel
Reduced synchrony in ecological systems	Lynx-hare cycle

The processes outlined above suggest the need for strategies to ensure sufficient adaptive capacity in the Clay Belt furbearer community, and its users. For example, since furbearers are harvested, the potential for species turnover suggests that the Ontario Ministry of Natural Resources needs to be prepared to alter harvest seasons to ensure appropriate and sustainable harvest. Alterations may include adjusting or closing seasons for currently harvested species, and adding new seasons for colonizing species. Models for harvest management may also need to be adjusted. For example, lynx are currently harvested under the paradigm of a 10-year cycle, which implies cyclical changes in allowable harvest among years, and this may need to change to a more stable harvest paradigm if lynx cyclicity is reduced. Seasons may also need to be adjusted to account for changes in breeding dates, especially for harvested rodent species. In the recommendations section below, we outline additional strategies to increase adaptive capacity of furbearers in the Clay Belt to changes in climate.

For a variety of reasons, we have not addressed many topics within the furbearer theme. In some cases, we had inadequate data for scenario modelling. For example, many furbearers are limited by deep snow (e.g., Krohn et al. 1995), but our ability to model snow depth for future climate scenarios is poor. We identify some additional areas of uncertainty in the recommendations section.

Generally, we envision a future in the Clay Belt whereby its constituent furbearer species gradually become more representative of temperate environments. Some temperate species will be gained, and some cold-adapted species may be lost. Furbearers are relatively vagile, and should be able to move to where the climate is such that they can thrive. The Ontario Ministry of Natural Resources and its stakeholders will need to pay close attention to these changes in the coming years and be prepared to adapt their activities accordingly.

Recommendations

Adaptive management: Consider the four processes leading to vulnerability of furbearers as hypotheses, and use an adaptive management framework to measure predicted changes in indicators associated with these processes. In Table 3 we have identified the processes leading to vulnerability of furbearers in the Clay Belt and provided a list of potential indicators.

Education and awareness: Ensure that stakeholders in the Clay Belt, including trappers, naturalists, and the public, are educated about anticipated changes in the furbearer community. This includes raising awareness of new furbearer species on the landscape, as well as novel pathogens. The latter may be especially important for trappers who are regularly in close contact with animals and may be susceptible to effects of the pathogens.

Managing harvest: Prepare to adjust fur harvest seasons or quotas. As species turnover occurs, harvest seasons may need to be opened or closed, or season lengths may need to be adjusted to accommodate changes in phenology. Season and quota changes can be made using adaptive management, whereby changes are used to test the management hypothesis with the goal of harvest sustainability.

Research needs: (a) Test the hypothesis that rapid climate change will select for species with higher genetic variability for fitness traits. Identifying genetic variability of fitness traits for furbearers should be a research priority. (b) Develop methods to model snow depth. Climate change scenario models that include snow depth as a model output should be a research priority.

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Appendix 1. Glossary of Terms

Adaptive capacity	The whole of the capabilities and resources of a country, region, community or group to implement effective adaptation measures; a synonym for resilience.
Biotic	Living or biological in nature.
Congeneric	Species belonging to the same genus.
Climate envelope	A description of the climate within which a species can persist.
Climate model	A quantitative description of the interactions between the atmosphere, oceans, and land surface. Assumptions about these interactions are used to forecast how changing CO_2 levels will affect future climate.
Community	A group of interacting populations.
Fitness	Net reproductive rate (as influenced by age at first breeding, birth rate and survival rate).
Foot-loading	Ratio of body mass to total foot area.
Gene flow	The movement of genes among different populations of a species.
Heritable	Capable of being passed from one generation to the next.
Hybridization	Successful interbreeding between two different species, subspecies, or populations.
Keystone species	A species whose role in an ecological community is critical, as their activities determine community structure.
Landscape resistance	A measure of a landscape's permeability to animal movement or gene flow.
Neonate	A newborn individual that is the product of a live birth.
Neuroendocrine	Relating to nerve cell transmission and the release of hormones.
Panmictic	In relation to a population of a species where all individuals are potential partners; that is, there are no genetic or behavioural restrictions on mating.
Pathogen	An organism that causes a disease within another organism.
Phenological	The seasonality of recurring animal and plant life events.
Photoperiod	The period of time that an organism is exposed to sun.
Population	A group of individuals of a single species in a particular area.
Scenario	A hypothetical state used to aid understanding of the potential effects of climate change.
Species richness	The number of different species in a defined area at a particular time.
Synchrony	A concordance between or among processes.
Taxonomic	Classification based on shared physical or genetic characteristics.
Vagile	Endowed with freedom of movement.

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